Dynamic linear calibration method for a wide range neutron flux monitor system in ITER

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Abstract As a key part of the diagnosis system in the International Thermonuclear Experimental Reactor (ITER), the neutron flux monitor (NFM), which measures the neutron intensity of the fusion reaction, is a Counting-Campbelling system with a large dynamic counting range. A dynamic linear calibration method is proposed in this paper to solve the problem of cross-over between the different counting and Campbelling channels, and improve the accuracy of the cross-calibration for long-term operation. The experimental results show that the NFM system with the dynamic linear calibration system can obtain the neutron flux of the fusion reactor in real time and realize the seamless measurement area connection between the two channels.

Key words Dynamic linear calibration, Long-term stability, Cross-over, Neutron flux monitor, International Thermonuclear Experimental Reactor (ITER)

1 Introduction

As a key diagnosis system in International Thermonuclear Experimental Reactor (ITER), neutron flux monitor (NFM) can provide the global neutron source intensity, fusion power, and neutron flux in real time[1]. To enlarge the measurable range of the neutron flux, the NFM can work in three different modes, including pulse mode for count rates less than 10^6 count per second (cps), Campbelling mode (known as "fluctuation mode" or "mean square voltage mode") for count rates larger than 10^5 cps, and current mode for other higher counting rates[2–4]. The calibrations of the counting and Campbelling mode are necessary for the system to get the precise neutron flux, a good cross-over between the two modes is of equal importance. The counting mode is calibrated by the detection efficiency calibration of the fission chambers[5,6], and the Campbelling mode is further calibrated based on the calibration of the single neutron pulse charge.

It was impossible to calibrate the absolute efficiency for all types of fission chamber with different sensitivities in the NFM, but the experimental method can only calibrate the most sensitive fission chambers[7] which were used to calibrate others empirically as the references[3]. The calibration for the single neutron pulse charge in Campbelling mode has been studied, indicating that the most calibration in a neutron environment is similar to the one by detector[3]. However, it is difficult to provide such a neutron environment for ITER as one of the largest controllable nuclear fusion reactors under construction. The absolute measurement uncertainty of the total fusion neutron yield should be less than 10% for the NFM[1]. It is difficulty to meet the requirement for the previous cross-calibration methods. For instance, the uncertainty of cross-calibration in the Tokamak Fusion Test Reactor (TFTR) can reach 10%[8]. The aging of devices for long-term operation in the NFM should be evaluated, such as the fission chamber, the preamplifier, the main amplifier and the Campbelling Integrator. The environment temperature and the

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generated heat of the electronic devices cannot be ignored because the NFM can reach 300°C[7]. So the cross-calibration for the Campbelling mode for the NFM are still researched.

In designing the wide range Counting-Campbelling NFM system, the Dynamic Linear Calibration (DLC) method was proposed to calibrate the Campbelling mode and eliminate the influences of cross-calibration on the measurement accuracies. The counting mode was measured in the range of 0–10^6 cps; and Campbelling mode, 10^4–10^8 cps.

2 Design of the wide range NFM system

The system must provide a dynamic range of 10^8 cps, a time resolution of 1ms and an uncertainty of less than 10% to measure the absolute neutron flux. The designed frame diagram of the NFM system is shown in Fig.1. The field experiment of the NFM system is shown in Fig.2. The NFM consists of two fission chambers with different sensitivities and an extra "blank" chamber. The "blank" chamber is fissile material free and has the same dimension with the fission chambers, so it can be used to identify the background rays such as gammas[1].

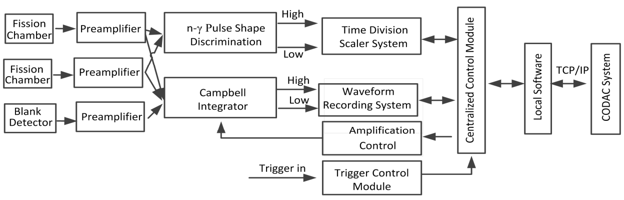

Fig.1 Schematic view of the system.

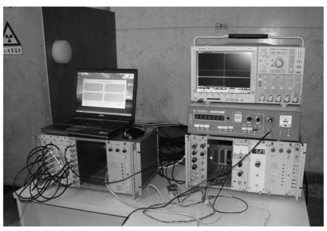

Fig.2 ITER NFM system in the field experiment.

The most difficult part of the NFM system is to get rid of the α and γ rays and other noise rays accompanying the neutron in the thermonuclear fusion reaction[9,10]. The pulse shape discrimination technology is usually adopted to distinguish between neutrons and gammas[11]. The *n*–*γ* Pulse Shape Discriminator (n–γ PSD) is designed for the measurement range of 0–10^6 cps when little pulse pileup occurs. It extracts the rising time and the amplitude of the pulse and judges whether it is from neutron or gamma, and only sends the neutron pulse to the Time division scaler unit for processing. Thus the count rate from the scaler unit represents the pure neutron flux.

The Campbell Integrator, which integrates the input signal, is designed for the measurement range of 10^4–10^8 cps when the pulse pileup situation has to be considered[12]. Based on Campbell theorem, the analog voltage output of the Integrator is proportional to the neutron flux[13]. The output voltage will be sent to the Waveform recording unit for processing.

The outputs of the Time division scaler unit and the Waveform recording unit, which represent the real-time neutron flux, are sent to the Centralized control module. The Centralized control module sends the results to the local software. The software transfers the neutron flux data to the CODAC system online in an interval of no longer than 1 ms for real-time feedback control.

3 DLC method

The output voltage of the Campbelling channel has to be converted to the count of neutrons. The problem is that it is hard to provide a neutron environment similar to ITER for the fission chamber calibration in Campbelling mode and the output voltage of the Campbelling channel is seriously affected by many factors, such as the baseline shift of electronic device, the temperature drift and the aging of the electronic device and the fission chamber. These problems cannot be avoided in the long-term performance, so we developed the DLC method.

Two points are selected in the overlapping measurement range, 10^4–10^6 cps, of the counting and Campbelling channel, the outputs of the two channels at the two points are obtained, respectively, and fitted by a linear equation as following:

$$F_{\mathrm{neutron}}=A + BV_{\mathrm{amp}} \tag{1}$$

where F_{neutron} is the output of the counting channel, which represents the true input neutron flux. V_{amp} is the voltage of the Campbelling channel. The formula describes the relationship between the input neutron

flux and the output of the Campbelling channel in the range of 10^4–10^6 cps. The Campbelling channel is a linear system, so we can transfer the analog output of it into neutron flux in the range of 10^4–10^8 cps.

In addition, the DLC method is easy to use and can be dynamically completed in the experiment. When the neutron flux in the experiment is in the overlapping measuring range of 10^4–10^6 cps, two points or more can be selected automatically or manually via the software. The software can select the suitable channel according to the level of the neutron flux. The correction coefficients A and B can be used immediately or in later experiments if necessary.

The DLC method avoids the problem of finding a neutron environment similar to ITER for the fission chamber calibration in Campbelling mode, and makes the system much more adaptable to different environments, and improves the long-term performance of the system. The coefficient A eliminates the influence of the baseline drift and the device aging. The coefficient B greatly improves the ability of adjusting the amplifier gain which is usually changing with the temperature and the device aging. The accuracy of experiment is significantly improved.

4 Tests and Results

The data obtained from the field experiments shows a typical neutron pulse with parameters as following: rise time T_r =80 ns, fall time T_f = 160 ns, $FWHM$ (Full Width at Half Maximum) = 160 ns, and amplitude V_i = 100 mV. The signal was imitated using the signal generator in the lab and used to test the NFM system.

First, the n–γ PSD and the Campbell Integrator are tested with the signal from the signal generator. The results are shown in Figs.(3) and (4). The output F_{neutron} of the n–γ PSD is equal to the frequency of input pulse when the input frequency is below 3 MHz.

The DC level is used to represent the pileup neutron pulse signal. The DC voltage sent to the Campbelling Integrator is changed from 10 mV to 2000 mV. The test result is shown in Fig.5.

The area of one neutron pulse simulated by signal generator is: $S_1 = FWHM \times V_i = 1.6\times10^{-8}$ Vs. The area of one 1mV DC level in 1 s is: S_2=1 mV×1s =0.001 Vs. The proportional coefficient $N = S_2/S_1 = 6.25\times10^4$, So 1 mV DC level signal has the same area with the 6.25×10^4 neutron pulses in 1 s. Through this equation we convert the input DC voltage in Fig.5 into the input pulse frequency, from 6.25×10^5 cps to 1.25×10^8 cps. The input pulse frequency in Fig.4 is from 10^4 cps to 3×10^6 cps. We integrate the two input pulse frequency ranges together and get the curve 2 in Fig.6, which shows the relationship between the input signal frequency and the output voltage of the Campbelling Integrator. The controllable signal attenuator is used in the Campbell Integrator. The output voltage in Curve 2 is the product of attenuation ratio and the real output of Integrator device.

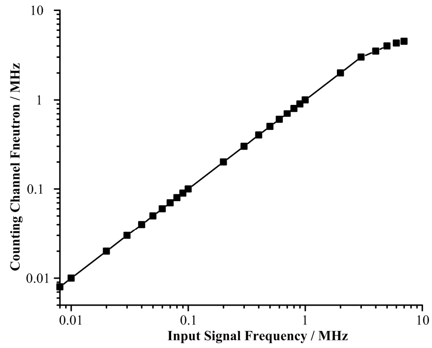

Fig.3 Relationship between the output of n-γ PSD and the input signal frequency.

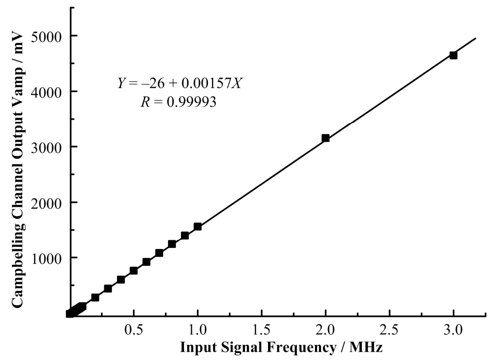

Fig.4 Relationship between the output of Campbell Integrator and the input signal frequency.

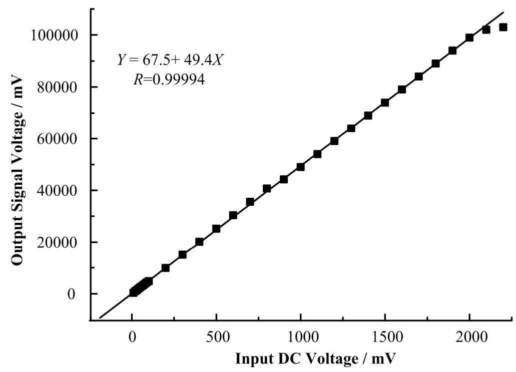

Fig.5 Relationship between the output voltage and the input DC voltage of the Campbell integrator.

Two points of P_1 (500 KHz, 380 mV) and P_2 (1000 KHz, 780 mV) are chosen in Fig.6. Fitted by Eq.(1), A=25 000 and B=1 250 are obtained, thus converting the output voltage of the Campbelling Integrator into the neutron flux. As shown in Fig.7, the linear dynamic value of the NFM system reaches 1.25×10^8 cps, and its linear correlation coefficient is 0.99995, solving the cross-over between two channels.

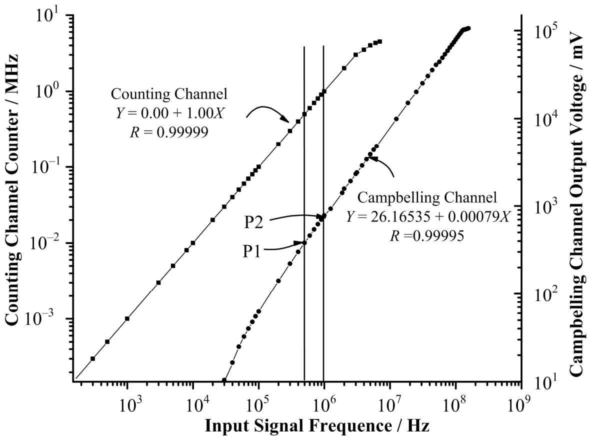

Fig.6 Input-output relationship of the Counting and Campbelling channel.

5 Conclusion

In order to measure the 0–10^8 cps in the NFM system, the counting-Campbelling system has been designed. The developed DLC method is easy to solve the cross-over between the channels of counting and Campbelling. The DLC method improves the accuracy of the cross-calibration and makes the system much more adaptable to different environments by improving the ability of eliminating the effects of the baseline drift, temperature change and the device aging. The NFM system of ITER has passed the test in the laboratory using the simulated neutron signal. We also have carried on the union testing in the steady neutron radiation field cooperated with the fission chamber and the preamplifier. The experimental result shows that NFM system achieved anticipated goal.

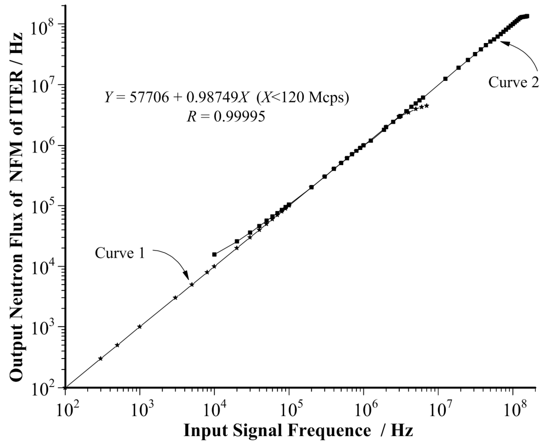

Fig.7 In-out relationship of the NFM system.

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